Engineering of photorefractive polymers

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CThK3 (Invited) **1600**

Active subjects in optical computing

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The situation of optical computing has changed dramatically over the last few years because of the development and availability of at least three complementary technologies that now open the way to applications to the parallel processing of a large amount of information.

The well known generation of nematic liquid crystal devices is now being complemented by the faster ferroelectric devices. (See the talks by W. Crossland in this topic area and by J. L. de Bougrenet in topic area 11.) Both optically addressed and electrically addressed light valves are commercially available, with switching times of the order of 10 μs. Considering the large parallelism that they offer, their computing throughput is significant.

The development of compound semiconductor device technology is getting close to the level of integration, sophistication, and energy efficiency required for applications. One leading figure in the domain is the self electro-optic device (SEED) family, at present the only commercially available component that offers optical nonlinear operation on an array of sites; recent developments include the combination of electronic functions with SEED devices into "smart pixel arrays." (See the talk by F. C. McCormick in this topic area.) Another recent example that is legitimately receiving significant attention at this meeting is the pnpn optical photothyristor array. (See the contributions by P. Heremans, G. Borghs, and coworkers in this topic area).

The photorefractive effects in sillenites, perovskites, and in III-V compound semiconductors is now well understood and their crystal growth issues are under control. This allows a predictable and reproducible behaviour in the writing and selective erasure of a large number of independent holograms in the same volume. (See topic area 6).

In these conditions, the field is open to imagination for the definition of competitive architectures using optical computing. The present discussion is restricted to free space optics. Four approaches will be distinguished.

The first challenge appears to be the application of optical computing devices to alleviate interconnection difficulties in computing and switching systems. Industrial applications are open to multistage switching networks that allow hundreds of nodes of one parallel machine or of a telecommunication unit to establish arbitrary communication channels in a submicrosecond time.

A general purpose optical computer has now been demonstrated. Performance improvement relies on fast, parallel access to a large memory that can flood the two-dimensional processor array with at least kilobits of data and instruction codes every few manoseconds. Other applications for optical memories, of course, are the parallel access to mass memories.

Optical analog processing has been following an independent line of progress: given that conventional optical systems easily accommodate parallel Fourier transformation and convolution over millions of pixels, can effective pattern recognition tasks on real scenes be performed by this approach? Recent works have shown that, at least in a number of realistic cases, the required invariances, selectivity, and noise robustness can be attained without loss of parallelism. With the present performances of spatial light modulators, this subject retains its competitivity. In the perspective of neural networks, the convolution is replaced by a matrix multiplication and the potential parallelism of optical systems is reduced to thousands instead of millions because of the space variance required. Nevertheless, because of the complexity of any architecture that requires fully arbitrary, reprogrammable analog interconnects amongst thousands of sites, the optical solution may still prove fruitful and useful at some future stage.

The combination of analog and digital functions into a massively parallel array of processors is a conceptually straightforward, but practically quite challenging, extension of the above ideas. It might lead, for example, to hybrid optical/electronic cellular automata for the video-real time image understanding, including robust texture analysis, motion analysis, and segmentation as well as pattern recognition. One example that is presently being developed in the author's group involves work on parallel algorithms for edge detection in noisy gray level images using stochastic algorithms, the optical production of the random numbers for the parallel implementation of the stochastic algorithms, optical convolution by specified kernels, and thresholding logic by pnpn photothyristor arrays made by IMEC in Leuven. In other words, the future of optical computing may lie in parallel vision machines and the potential markets for such a machine are obviously significant.

Assuming progress on active devices and on system definition, the practical integration of these systems remains a major challenge. Modern solutions include the etching of arbitrary interconnect functions using diffractive optics and total internal reflection imaging and the standardisation of microlens array and beam splitter array fabrication techniques.

CThL 1500 Room B

Photorefractive Materials

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CThL1 (Invited) **1500**

Engineering of photorefractive polymers

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Photorefractive polymers offer advantages such as their considerable flexibility in synthesis, doping, processing, and low cost. Furthermore, compared to their crystalline counterparts, they offer the possibility of improved value in the photorefractive index change figure-of-merit n^3-r/ϵ, owing to the small dc dielectric constant ϵ and reasonable linear electrooptic coefficient r and refractive index n.[1]

The required functionalities responsible for photorefractivity, namely charge generation, transport, trapping, and linear electrooptic effect are given in the polymer with the addition of specific molecules or monomer. In this way, engineering of the properties of a photorefractive polymer and optimization for a specific application can be done via chemical synthesis.

We have investigated both host-guest (e.g., photoconducting polymers like PVK:TNF doped with electrooptic molecules or electrooptic polyurethanes doped with charge transporting molecules like DEH and sensitizers like TNF and C_{60}) and single component (where all the necessary functional components are covalently bonded on the same polyurethane backbone) polymer materials. Various trade-offs that exist in photorefractive polymers have been examined.

All the photorefractive polymers that have been reported until today[2] show a strong absorption in the visible and as a result, the range of wavelengths used to study their properties has been mainly limited in the red-near infrared part of the spectrum. With the proper selection of the functional components, we have made host-guest polymers optimized to show net gain and subsecond response at various laser lines in the visible part of the spectrum. This is especially important, as in order to be advantageous for

applications, a photorefractive material should have a large range of wavelengths where it can be used. Especially where information storage density is concerned, response in the visible is preferable.

In order to maintain the photorefractive effect in a polymer, a noncentrosymmetric arrangement of the electrooptic molecules should be achieved. For this reason, the continuous application of an external electric field is necessary, as these molecules relax in a centrosymmetric arrangement when this field is switched off. We have prepared a novel class of single component polyurethane-based materials that can sustain permanent orientation of the electrooptic molecules and studied its photorefractive properties.

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CThL2 **1530**

Electro-optic, dielectric, and elasto-optic properties of photorefractive $BaTiO_3$ crystal

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Measurements on high quality samples of top-seeded-solution-grown crystal $BaTiO_3$ have been performed in order to complete the set of data, which is necessary to describe the optic response of this material to electric fields and elastic deformation.[1] Improvements in the accuracy of some previously published results could be obtained because of better optical quality and larger size of the crystal samples that are available nowadays. The most important results are the values and the signs of the piezoelectric coefficients d_{311} and d_{333}, the absolute values of the elasto-optic coefficients, and all the electro-optic measurements. Both low frequency electro-optic measurements in a stress-free sample and the measurements in the inertia-clamped samples using a step-like electric field were used to correct the previous results. The complete set of material parameters of the $BaTiO_3$ crystals at room temperature has been afterwards determined by a numerical fitting procedure. The signs of the elasto-optic coefficients could also be determined with great confidence. We propose that the new calculated values are used as a consistent set of material parameters of the $BaTiO_3$ crystal, in particular for describing its photorefractive properties, that is, to calculate its effective electro-optic and dielectric properties.

In order to demonstrate the benefits of the newly determined complete set we calculate effective electro-optic coefficients and dielectric constants of $BaTiO_3$ in photorefractive experiments, where the elastic deformations associated with a periodic space-charge field have to be considered.[2-4] We show that a complete knowledge of the material parameters of a photorefractive crystal is necessary. The newly determined values for the effective electro-optic and effective dielectric constants of barium titanate for the most common photorefractive geometries are considerably different from the values that have been used until now.

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CThL3 **1545**

Shallow trap modelling of infrared sensitive $BaTiO_3$

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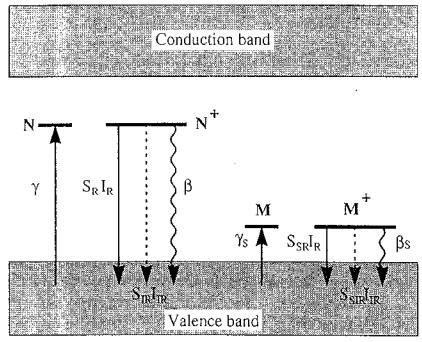
Recent interest in photorefractive $BaTiO_3$ has turned toward near infrared wavelengths compatible with solid-state laser diodes. The demonstration of applications, such as diode injection locking and brightness enhancement[1] in this region of the spectrum using modest laser powers has renewed interest in the ferroelectric material.

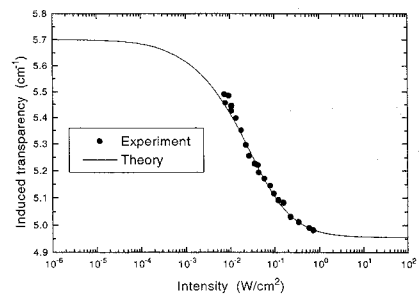
Infrared sensitive $BaTiO_3$ has been reported recently[2] using crystals, blue in colour, which possess enhanced absorption in the red and near infrared regions of the spectrum. Although the impurity responsible for the blue colour and enhanced photorefractive behaviour was unknown at the time, recent attempts to identify the dominant photorefractive centre has suggested that rhodium (in the valence states Rh^{3+}/Rh^{4+}) may be responsible.[3]

The single level band transport model most commonly used to describe photorefractive behaviour has, despite its simple nature, met with considerable success in explaining many of the photorefractive effects observed. However, in order to account for more complex photorefractive phenomena, such as sublinear two beam coupling response time and intensity dependent absorption, model refinements have been suggested including the introduction of additional levels closer to the conduction (or valence) band edge.[4] The addition of these shallow traps is of concern for longer wavelength infrared compatibility of photorefractive crystals where the lower energy photons are capable of photoexcitation. The model (illustrated in Fig. 1) assumes that the photoexcitation coefficient for both deep and shallow traps is wavelength dependent. Numerical modelling of the shallow trap rate equations has allowed various parameters to be derived from the experimental points measured at infrared, red, and blue wavelengths.

Photoinduced absorption was assessed by measuring the transmission of



CThL3 Fig. 1. Shallow trap photorefractive model. Deep trap parameters: N, number density of traps; N^+, number density of ionised traps. Photoexcitation, thermal excitation, and recombination coefficients s, β, and γ, respectively. Shallow traps: M, number density of traps; M^+, number density of ionised traps. Photoexcitation, thermal excitation, and recombination coefficients of s_s, β_s, and γ_s, respectively. Additional subscripts, R and IR, refer to red (633-nm) and infrared (800-nm) illumination, respectively.



CThL3 Fig. 2. Light induced transparency at 633 nm. The experimental data is plotted alongside the theoretical curve obtained by numerical modelling.

an o-polarised HeNe (633 nm) beam through the blue crystal (dimensions 7.27 × 3.01 × 5.64 mm^3 with the crystal c-axis parallel to the 5.64 mm edge). The observed changes in the apparent absorption through the 3.01 mm thickness were characterised by an initial rapid decrease followed by a slow recovery (a few seconds) consistent with previous observations.[5] The timescale of the process was intensity dependent: occurring faster for higher intensities. Figure 2 shows a plot of the maximum change in the absorption with the logarithm of the incident HeNe intensity. The graph indicates an apparent intensity dependence of the absorption. The solid line shown in Fig. 2 is the best fit curve using the numerical simulation of the shallow trap model.

In addition to intensity induced transparency, light induced absorption has also been observed. The crystal was first exposed to a 1-mm-diameter, 6.7-mW o-polarised HeNe laser beam—the intensity of which remained constant throughout the experiment near the saturation limit according to Fig. 2. The transmission of the HeNe beam was then moni-